

INVESTIGATION OF AIR TRANSPORTATION TECHNOLOGY
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Robert W. Simpson
Flight Transportation Laboratory
Massachusetts Institute of Technology
Cambridge, Massachusetts

INTRODUCTORY REMARKS AND OVERVIEW

There were two areas of research sponsored under the Joint University Program during 1985. The first is the investigation into runway approach flying with Loran-C, involving flight tests in a Grumman Tiger. The second is a series of research topics in the development of experimental validation methodologies to support aircraft icing analysis, which also has involved flight tests in the Twin Otter Icing Research Aircraft at NASA Lewis Research Center.

1. RUNWAY APPROACH FLYING USING LORAN-C

This project is aimed at exploring the capabilities of Loran-C to provide cross-pointer approach displays for the general-aviation pilot which can be used to fly approaches to any runway located in good Loran-C signal coverage. Cross-track and vertical deviations from the runway centerline are derived from a Loran-C local coordinate frame centered on the runway touchdown point, thus avoiding any transformation into geodetic latitude and longitude and allowing an easy update of current time differences at the airport, as recorded from a monitor at the airport. Vertical deviations are derived from Loran-C estimates of range to touchdown, given the glide slope, and a digitized electronic pressure altimeter.

The first phase of research work was completed by John K. Finhorn, resulting in his S.M. thesis entitled, "Probabilistic Modeling of Loran-C from Non-Precision Approaches." This phase formulated a mathematical model of expected position errors for a Loran-C approach at a given runway located relative to the Loran-C transmitter. From this position, error ellipses were generated, corresponding to two time difference correction schemes. The first involved relaying corrections to the pilot just before he initiated the approach, and the other involved publishing corrections on the instrument approach plates every few months. It was found that both schemes provided errors well within the FAA AC 90-45A accuracy standards, and that the first scheme was a significant improvement over the latter.

Flight tests in Phase I were conducted in the Grumman Tiger, carrying an equipment test bed designed to take data from a Loran-C receiver and instrument landing system (ILS) localizer receiver. These tests were flown at four different airports within the 9960 Northeast chain of domestic Loran-C coverage: Hanscom Field at Bedford, Massachusetts; Groton, Connecticut; Newport, Rhode Island; and Bar Harbor, Maine. Differences from the ILS localizer averaged 0.65° (equivalent to 97 feet at runway threshold or 270 feet at the outer marker of the approach), and the Loran-C appeared to provide very good localizer tracking. It was concluded that Loran-C is a suitable system for non-precision approaches, and that time-difference corrections made every eight weeks in the instrument approach plates will produce acceptable errors.

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The second phase of the Loran-C research is continuing with the work by Norry Dogan. It is exploring the possibilities of pseudo-precision approach flying, using an altimeter-aided display system to provide both cross-track and vertical deviations from the approach centerline and glidepath. An electronic approach display system has been built, and an interface has been provided with a King Radio KEA-346 altimeter. The tracking dynamics of the Loran-C receiver have been tested in ground vehicle trials and can be modeled as a second-order system with a damping ratio around 0.5 and a time constant of approximately 18 seconds. Preliminary flight tests have been flown at Hanscom Field, Bedford, Massachusetts, showing that Loran-C approaches can be flown using an approach display based on Loran-C. However, further tests are contemplated to eliminate various deficiencies found in the operation of the system.

A highlight of the year was the announcement that the W. E. Jackson Award for the best student thesis had been awarded to John Einhorn by the Radio Technical Commission for Aeronautics. It is available as MIT FTL Report R85-5 (Reference 1).

2. EXPERIMENTAL METHODOLOGIES TO SUPPORT AIRCRAFT ICING ANALYSIS

Research efforts in this area stem from original work sponsored by this program on the demonstration of the use of ultrasonic transducers to measure accurately the thickness of a layer of ice on a surface. As described in Reference 2, an ultrasonic pulse is emitted from the transducer and reflects off the ice/air interface to be detected by the transducer acting as a receiver. Since experiments have shown that the speed of sound in various types of aircraft ice is constant, the time lapse can be used to determine ice-layer thickness above the transducer imbedded in the surface. Accuracies greater than a millimeter are possible, and ice accretion rates over time can be determined even if they vary. It is possible to identify whether there is a layer of water present at the ice/air interface.

After tests in the Icing Research Tunnel at NASA Lewis Research Center which measured ice accretion on a circular cylinder at light and heavy, wet, dry, rime or glaze conditions, similar cylinder flight tests onboard the Twin Otter Icing Research Aircraft were conducted in real icing conditions. The increased accuracy allowed measurement of icing rates in terms of mm/min (instead of inches/hour from other means) and allowed a good correlation to be established with the time variation in liquid water content of the icing cloud, as measured by onboard instrumentation. While development of improved ultrasonic detection systems continued during the year in the form of an array of small transducers to be mounted around a cylinder or leading-edge glove mounted on the aircraft wing and a high-speed digital data acquisition system, the real objectives of the research project are to develop a model which explains the role of various parameters in aircraft ice accretion.

A simple steady-state heat-transfer model was used to validate the heat-transfer data used by Lewis Research Center. Accretion rates in wet and dry conditions at various cloud temperatures were consistent with experimental results. Small-scale air turbulence in the tunnel was used to show that turbulence was significantly lower in real flight conditions. The role of sublimation was identified. It is important as a heat-transfer mechanism, and the decrease in ice thickness in clear air due to sublimation was shown to be less than 1 mm per hour.

Further Twin Otter wing glove flight tests are being planned to obtain time and space ice-growth data. These flight test data will be compared with analytical prediction for computational models and scaling analysis. In addition, the instrumented glove will be tested in the Icing Research Tunnel.

These data sets will provide a unique opportunity for the direct comparison of the various icing analysis and certification tools currently in use.

ANNOTATED REFERENCES

1. Einhorn, John K., "Probabilistic Modeling of Loran-C for Non-Precision Approaches," MIT FTL Report R85-5, Flight Transportation Laboratory, MIT, Cambridge, MA 02139, 1985.

This report creates a model for expected position errors at a runway approach located in a given Loran-C triad. Expected position-error ellipses were generated for two correction schemes for Loran time differences. The "update each approach" scheme was shown to be significantly better than the "publish approach plates every eight weeks" scheme, although the latter was well within the accuracy standards called for by FAA AC90-45A for non-precision approaches. Flight tests at four different airports in the 9960 Northeast USA Loran-C chain demonstrated the flyability of the Loran-C localizer path, and showed an average error of 0.65 degrees between ILS localizer and Loran-C data.

2. Hansman, R. John, Jr. and Kirby, Mark S., "Measurement of Ice Accretion Using Ultrasonic Pulse-Echo Techniques," J. Aircraft, vol. 22, No. 6, June 1985.

Results of tests to measure ice thickness using ultrasonic pulse-echo techniques are presented. Tests conducted on simulated glaze ice, rime ice, and ice crystals are described. Additional tests on glaze and rime ice samples formed in the NASA Lewis Icing Research Tunnel are also described. The speed of propagation of the ultrasonic wave used for pulse-echo thickness measurement is found to be insensitive to the type of ice structure, and is determined to be 3.8 mm/ μ s. An accuracy of ± 0.5 mm is achieved for ice thickness measurements using this technique.

ANNOTATED BIBLIOGRAPHY

1. Hansman, R. John, Jr., "Measurement of Individual Hydrometeor Absorption Cross Sections Utilizing Microwave Cavity Perturbation Techniques," J. of Atmospheric and Oceanic Technology, vol. 1, No. 4, December 1984.

A technique for measurement of individual hydrometeor absorption cross sections is presented. Cross sections are inferred by inserting the hydrometeor into a high Q resonant cavity and measuring the Q perturbation. Tests were conducted in a 10.64 GHz, TM_{010} cavity. Absorption cross sections were measured at room temperature for 0.5 to 2.0 mm water drops, and were found to agree with the Rayleigh theory. Cross sections were also measured as a function of temperature, and from these the dielectric loss term $\text{Im}(-K)$ was inferred for supercooled water down to -17°C .

2. Hansman, R. John, Jr., "Droplet Size Distribution Effects on Aircraft Ice Accretion," J. Aircraft, vol. 22, No. 6, June 1985.

The impinging mass flux distribution which determines aircraft ice accretion rate is shown to be related to the atmospheric droplet size distribution through the droplet collection efficiency of the body. Collection efficiency is studied by means of a two-dimensional droplet-trajectory code which includes the effect of nonspherical droplet shape due to hydrodynamic deformation. The simulation was found to agree with wind tunnel photographic studies of droplet kinematics. The results of the simulation are used to generate impinging mass flux distributions for typical cloud and precipitation size distributions. The impinging mass approach is also used to determine relative icing rates from several supercooled cloud characterizations including the intermittent maximum icing envelope of Federal Aviation Regulation, Part 25.